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EFFECTS OF LOWERED WATER TEMPERATURE ON THE SURVIVAL AND BEHAVIOR OF JUVENILE FRENCH GRUNT, *HAEMULON FLAVOLINEATUM*

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Temperature reduction associated with natural events or developing technologies may cause substantial impacts in subtropical waters. Natural cold water intrusions have recently been postulated as the cause of mass fish kills.[1] Artificial mixing of cold water (< 10°C) with tropical surface layers is likely if Ocean Thermal Energy Conversion (OTEC) is developed as an alternative source of electrical energy. Impacts of such cold water intrusion are difficult to evaluate because no data are available. Cold shock data are limited to effects measured on juveniles and adults in temperate climates.

The specific objectives of this study were to evaluate a simple technique for

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[1] Gulf and Caribbean Fisheries Institute. 1981. Unusual mass fish mortalities in the Caribbean and Gulf of Mexico, an ad hoc symposium, Mayaquez, Puerto Rico, 1981. Prepared by the Atlantic Oceanographic and Meteorological Laboratories, Miami, Florida. 46 pp.

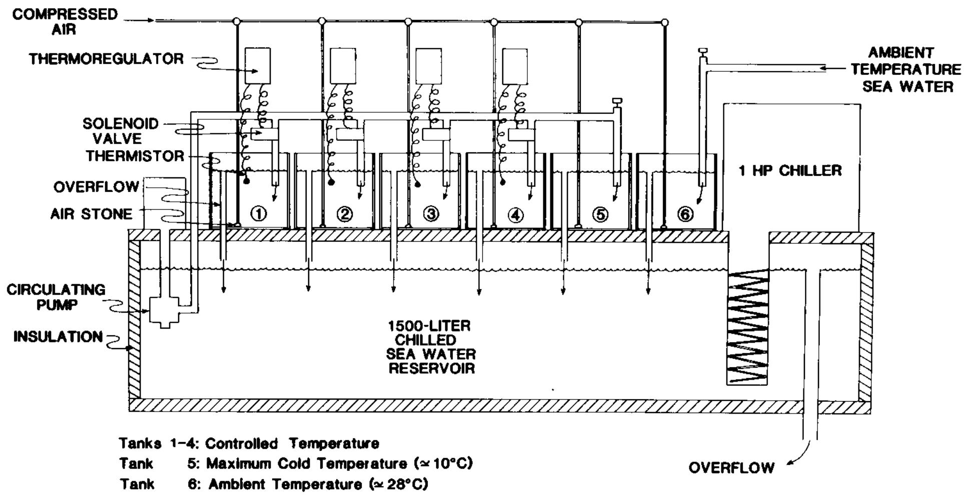

Figure 1. Diagrammatic representation of the test apparatus. Transfer vessel in which fish were held inside of tanks is not shown.

determining the effects of cold shock on the survival of early life stages of tropical fish by testing this technique on juvenile French grunt, *Haemulon flavolineatum* (Desmarest). French grunt were chosen for this study because of their importance in the Caribbean fishery (Weiler and Suarez-Caabro, 1980) and their occurrence at potential OTEC sites.

Materials and Methods

Juvenile French grunt used in this study (approximately 30–80 mg wet weight and 15 to 20 mm TL) were collected by SCUBA divers with dip nets along the island side of Tague Bay Reef fringing the northeast end of St. Croix, U.S. Virgin Islands. Fish were transferred from the dip net to holding containers under water, then transferred to the laboratory within 1 h of capture. In the laboratory the fish were held in flowing water at ambient temperature and salinity and natural light conditions for 24 h before use. Fish in holding tanks and in experiments were fed brine shrimp nauplii, *Artemia salina,* twice a day from the time of capture to the end of the experiment.

To minimize handling stress, special care was used so that fish were never out of the water while being transferred between tanks. A slight modification of the transfer method described by Hoss et al. (1974) was used. In the holding tanks, fish that swam into a capture bucket were moved to an immersed transfer bucket. When 10 fish had been captured, the transfer bucket was carefully removed so that most of the water drained out through a screened opening near the bottom, leaving only enough water to cover the fish. This technique reduced stress on the fish due to either mechanical damage or air exposure during the transfer process.

A diagrammatic representation of the test apparatus is given in Figure 1. A 1-hp saltwater refrigeration unit was used to cool a 1,500-liter reservoir tank to approximately 10°C. Cold water was pumped from the reservoir and distributed through solenoid valves to four experimental tanks. Each of these tanks contained a thermoregulator connected to the solenoid valve, which controlled the temperature (i.e., cold water flow) to the experimental tanks. All tanks were aerated to insure that the water was mixed. Using this system, experimental temperatures could be controlled to within ±0.2°C. The water in the system was continuously renewed by inflow of new ambient temperature seawater into the cold water reservoir at a rate of about 1 liter/min.

The main criterion used to evaluate cold shock was percent survival. This response was monitored for 72 h after shock of various durations at several temperatures starting from natural acclimation temperatures (about 28°C). The Δt's tested ranged from −10 to −18.5°C with most data from intermediate temperatures where we expected intermediate survival percentages. Three exposure times were used, i.e. 5, 15 and 30 min. Some of the Δt-exposure time combinations were replicated.

Behavioral observations on the response of the fish to the change in temperature were made and recorded during each experiment and also at additional lower Δt's. Loss of equilibrium, changes in

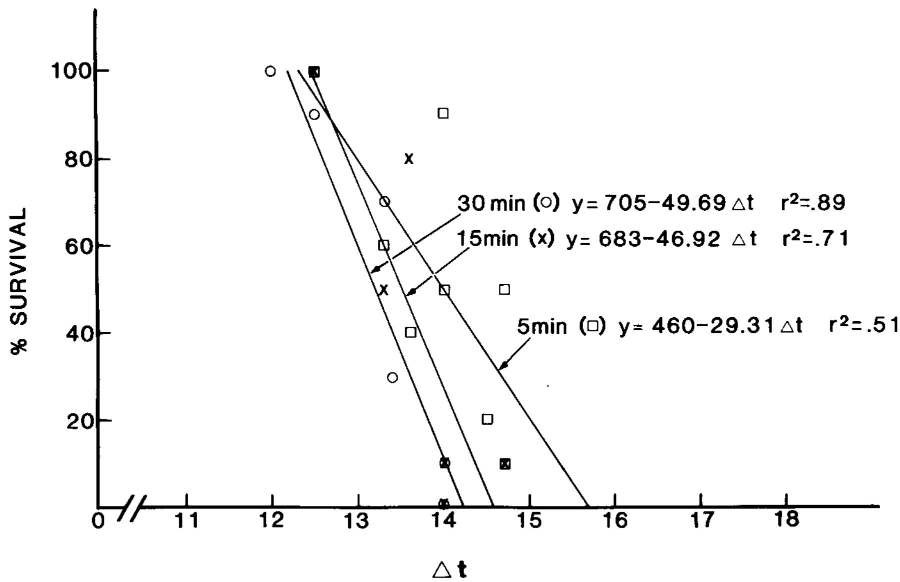

Figure 2. Percent survival of juvenile French grunt at 28°C, 24 h after exposure to temperature reductions (Δt) for 3 exposure times. Linear regression calculated using data from highest Δt at which survival was 100% and all higher Δt's for which survival still exceeded zero.

color, opercular "flaring," and feeding were four easily observed responses. In some cases, time required to regain equilibrium also was recorded.

Results

The survival of French grunt following cold shock was dependent on the Δt. No mortality occurred in the controls (fish transferred between containers, but not subjected to decreased temperatures) or at Δt's of −10 and −12°C (2 reps at Δt's of −10 and −12°C for each of the three exposure periods). Mortality first occurred at cold shocks slightly greater than −12°C regardless of the exposure time. At shock temperatures resulting in fractional survival it appears that mortality rate increases with exposure time (Fig. 2). However, due to variability we have not demonstrated a significant difference due to duration of impact. Mortality was 100% at Δt −18.5°C (5 min exposure) and −14.7°C (30 min exposure).

The initial response of French grunt to an abrupt decrease in temperature was a burst of swimming activity that occasionally included jumping out of the water;

Table 1. Behavioral response of French grunt juveniles that survive abrupt decreases in temperature (Δt) of −10 to −14°C

Behavior	Response time	Recovery time	Comments
Increased activity	Instantaneous	N/A	Rapid swimming at low Δt's; jumping
Loss of equilibrium	Seconds	Minutes	Dependent on Δt
Opercular flaring	Seconds	Minutes	Same as above
Color change	Minutes	Hours	Large amount of individual variation
Feeding	N/A	1 h	Surviving fish generally fed within 1 h after return to ambient temperature

Table 2. Effect of sub-lethal cold shock on the ability of French grunt juveniles to maintain equilibrium

Δt (°C)	No. tests (10 fish each)	Equilibrium loss (%)	Recovery in 2 minutes (%)
6.0	2	0	NA
6.4	1	30	100
7.0	3	63	100
8.0	2	65	100
9.0	4	82	80
10.0	2	100	0

then, in a matter of seconds (<30), the fish would settle to the bottom of the test container with the opercula flared, the body arched, and the color pattern generally more intense. The time the fish remained in a moribund condition when returned to ambient water varied depending on the Δt, and there was considerable variation among individual fish. The first sign of recovery was movement of the opercula. During continuous exposure at a Δt of −10°C, some fish regained their equilibrium after 4 min, and usually after 12 min, all fish would be upright. At greater Δt's, return to equilibrium was delayed, sometimes to 30 min. On their return to ambient water, the fish received a second thermal shock, but for those that had recovered in the cold water, the effect did not seem to be as severe as that of the original cold shock. A summary of the behavioral observations is presented in Table 1.

The percent of fish which lost equilibrium was closely related to Δt. The observations, summarized in Table 2, show that equilibrium loss occurs, at least in some fish, at a Δt of −6.4°C. At Δt's between −6.4 and −9°C, recovery of equilibrium is rapid, 2 min or less, for most fish.

Discussion

The techniques developed in this research were useful for determining the effects of cold shock on fish. Although juveniles were used in these initial experiments, the system could be used for eggs and larvae.

From our survival studies, we conclude that juvenile French grunt can survive acute cold shock to a temperature of 16°C (Δt −12°C) for at least 30 min with no mortality. When water temperatures dropped below 16°C, mortality rapidly increased and was dependent on exposure time. From our data and that of others (Porter et al., 1982), it appears that there is a rather abrupt thermal limit to survival for tropical reef species. It is interesting to note that Porter et al. (1982) reported that 96% of surveyed Dry Tortugas reef corals (mainly *Acropora cervicornis*) were killed by a natural intrusion of 14°C water. Our data indicate that the juvenile French grunt associated with the reef community would also have suffered high mortality if unable to avoid 14°C water.

Even though juvenile grunt in the laboratory were able to survive cold shock, the moribund condition produced by temperature changes greater than −6°C could increase their vulnerability to predation in field situations if cold water from an OTEC discharge or natural cold water intrusion flowed through juvenile French grunt habitat. Juvenile grunt typically occupy the back-reef habitats of coral formations (*Porites porites* and *Acropora palmata*) by day and the adjacent seagrass beds at night (Ogden and Ehrlich, 1977). Cold-shocked grunt, as they lay stunned on the bottom, would be easy prey for predators less susceptible to cold shock. The relative sensitivity to cold shock of possible predators (or scavengers) has not been determined. In the absence of viable predators, no significant mortalities should occur in French grunt after recovery from the temporary equilibrium loss.

We conclude that the direct effects of cold water shock (at Δt's of $-12°C$ or less) from OTEC plants on juvenile French grunt should not cause significant mortalities. Additional studies are needed, however, to determine the effects of reduced temperature on egg hatching and early larvae. Harada et al. (1978), for example, found that no yellowfin tuna larvae developed normally in temperatures below 20°C. Seasonal effects must also be considered, i.e., a $-12°C$ temperature change during the winter may be more important than the same change during the summer.

Based on our results and others (Porter et al., 1982; Bohnsack, 1983; Starck, 1970) on the sensitivities of coral reef organisms to lowered temperature, great care should be exercised in locating cold water discharge from OTEC facilities so as not to impact reef habitats.

Acknowledgments

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